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(54) **Therapeutic light source**

Therapeutische Lichtquelle

Source lumineuse thérapeutique

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Description

[0001] The present invention relates to a non-coherent light source for use in therapy such as photodynamic therapy (PDT), particularly using light emitting diodes (LED's).

[0002] Photodynamic therapy involves the administration of a photosensitising drug to an affected area, and its subsequent irradiation with light - see for example 'The Physics of Photodynamic Therapy' by B C Wilson and M S Patterson, Physics in Medicine & Biology 31 (1986) April No. 4, London GB.

[0003] The document GB 2,212,010 discloses a therapeutic light source which uses an array of discrete LED's as an alternative to lasers or laser diodes. The output of the LED's is focussed so as to provide the necessary intensity.

[0004] The document WO 94/15666 discloses a therapeutic light source specifically for PDT, with an integrated array of LED's mounted on the distal end of a hand piece. The LED's are overdriven to give the necessary intensity, and cooled by the flow of water around a closed loop passing along the hand piece. The document US 5728090 discloses a somewhat similar device with various different types of head containing integrated LED matrices. These devices require complicated liquid cooling circuits which would add to the cost of the device and add to the bulk of the hand piece, which is disadvantageous for invasive use.

[0005] The document US 5728090 mentions that the wavelength of the LED's is between 300 nm and 1300 nm and is selected based upon the particular photosensitive dye used during PDT. However, the wavelengths of LED's capable of providing the necessary intensity for PDT cannot freely be chosen within that range.

[0006] The document US 5634711 discloses a hand-held light-emitting device for phototherapy, comprising an LED matrix and a fibre optic taper or a lens for concentrating the light on a photoreaction area. The LED matrix is air-cooled.

[0007] The document WO 93/21842 discloses a high-power LED array for photodynamic therapy, which uses direct illumination of the target area. The centre wavelength of the emission band can be tuned using a preset operating current and the judicious use of cooling.

[0008] According to the present invention, there is provided a therapeutic light source according to claim 1. Specific embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a diagram of a parallel-series matrix of discrete LED's used in first and second embodiments of the present invention;
Figure 2 is perspective diagram of the first embodiment;
Figure 3 is a cross section of part of the first embodiment;
Figure 4 is a graph showing the variation of intensity in a cross-section of the output of the first embodiment;

[0009] Figure 5 is a graph showing the absorption spectrum of PpIX and the emission spectra of two examples of LED's suitable for use with the embodiment.

[0010] In a therapeutic light source in an embodiment, as illustrated in Figures 1 to 5, light is emitted from a parallel-series matrix of LED's L connected through a current-limiting resistor R to a source of a voltage +V. The LED matrix is mounted on a heatsink array H parallel to and spaced apart from a fan array F by support rods R. Air is blown by the fan array F onto the back of the heatsink array H.

[0011] As shown in more detail in Figure 3, the heatsink array H comprises a plurality of individual heatsinks h mounted on the ends of the legs of the LED's, which pass through a support plate P. Each leg is soldered to an adjacent leg of another of the LED's in the same column. The support plate P is perforated to allow air to flow more freely around the heatsinks h and the LED's L.

[0012] The LED's L are arranged so as to produce a substantially uniform illumination of ±10% or less across a treatment field by selecting the beam divergence and spacing of the LED's L so that their individual beams overlap without causing substantial peaks or troughs in intensity. In the example shown in Figure 4, uniformity of ±6% is achieved. In this embodiment, no optical system is needed between the LED's and the patient; instead, the light is emitted directly from the LED's onto the patient. As the light is not concentrated by any optical system, the LED's have individual power outputs of at least 5 mW and preferably at least 10 mW, to give the necessary fluence rates in the treatment field of at least 30 mW/cm^2 in the red region of the spectrum and at least 10 mW/cm^2 in the blue region.

[0013] In one specific example, a 15 cm diameter array of 288 'Super flux' LED's was used to produce a total light output of 8 W at 45 mW/cm^2 in the treatment field. The LED's were driven at a higher current load than their specification while being cooled by forced air convection from the fans F. In the specific example, the current was limited to 90 mA per column of diodes, but may be increased to 120 mA or more if increased light output is needed. The number of diodes in series, in each column, is selected so that the total forward operating voltage is as close as possible to, but less than, the power supply output voltage, in this case 48 V. This arrangement avoids wasteful in-circuit heating and maximizes the operating efficiency of the electrical system.

[0014] In a method of treatment using the device of the embodiment, the LED array is positioned approximately parallel to an external affected area of a patient to be treated, with a separation sufficient to achieve the uniform illu-

mination as shown in Figure 4, for example 2 to 5 cm. The device may be used for cosmetic or partially cosmetic treatment with a photosensitizing drug for portwine stain removal and hair restoration/removal, and without a photosensitizing drug for skin rejuvenation, wrinkle removal or biostimulation (including wound healing).

[0015] The lamp may also be used for fluorescence detection (photodiagnosis).

[0016] The selection of appropriate discrete LED's for PDT using the embodiment will now be described, grouped according to die material.

[0017] A first suitable type of LED is based on aluminium indium gallium phosphide/gallium phosphide (AlInGaP/GaP) of transparent substrate (TS) or absorbing substrate (AS) type. The output wavelengths are in the range 590 to 640 nm with peak emission wavelengths of 590, 596, 605, 615, 626, 630 and 640 nm. Commercially available examples are the 'SunPower'™ or 'Precision Optical Power'™ series from Hewlett Packard Company, designed for use in the automotive industry, for commercial outdoor advertising and traffic management. Suitable LED's are those packaged as: SMT (surface mount technology) e.g. HSMA, HSMB, HSMC, HSML series and preferably HSMB HR00 R1T20 or HSMB HA00R1T2H; Axial e.g. HLMA or HLMT series; T1 e.g. HLMP series, preferably HLMP NG05, HLMP NG07, HLMP J 105; T13/4 e.g. HLMP series, preferably HLMP DG08, HLMP DG15, HLMP GG08, HLMP DD16; Superflux™ e.g. HPWA or HPWT series, preferably HPWA (MH/DH/ML/DL) 00 00000, HPWT (RD/MD/DD/BD/RH/MH/DH/BH/RL/ML/DL/BL) 00 00000, most preferably HPWT (DD/DH/DL/MH/ML/MD) 00 00000; SnapLED™ e.g. HPWT, HPWS, HP-WL series, preferably HPWT (SH/PH/SL/PL) 00, HPWT (TH/FH/TL/FL) 00 or HPWS (TH/FH/TL/FL) 00. Suitable products from other manufacturers include: of SMT type, Advanced Products Inc. (API) part no. HCL4205AO; of T1 type, American Bright Optoelectronics (ABO) part no. BL BJ3331E or BL BJ2331E; of Superflux type, ABO part no.'s BL F2J23, BL F2J33 and BL F1F33.

[0018] A second suitable type of LED is the aluminium indium gallium phosphide/gallium arsenic (AlInGaP/GaAs) type, with emission wavelengths in the range 560 to 644 nm and peak emission wavelengths of 562 nm, 574 nm, 590 nm, 612 nm, 620 nm, 623 nm and 644 nm. Examples commercially available from Toshiba in T1 package are the TLRH, TLRE, TLSH, TLOH or TLYH series, preferably TLRH 262, TLRH 160, TLRE 160, TLSH 1100, TLOH 1100, TLYH 1100 or S4F4 2Q1; or in T13/4 package are the TLRH or TLSH series, preferably TLRH 180P or TLSH 180P. Another example is Kingbright L934SURC-E.

[0019] A third suitable type of LED is aluminium gallium arsenic type (AlGaAs), with emission wavelengths in the range 650 to 660 nm. Examples in T1 package include the Toshiba TLRA series, preferably TLRA 290P or TLRA 293P, and Kingbright L934 SRCG, L934 SRCH, and L934 SRCJ and in T13/4 package include Kingbright L53 SRCE.

[0020] A fourth suitable type of LED is gallium phosphide (GaP) type, with emission wavelengths in the range 550 to 570 nm.

[0021] A fifth suitable type of LED is indium gallium nitride (InGaN). In the type with an emission wavelength of 525 nm, commercially available examples include: in SMT package, API's HCL 1513AG; and in T1 package, Farnell's #942 467, Radio Spare's #228 1879 and #249 8752, API's HB3h 443AG and Plus Opto's NSPG500S. In the type with emission wavelengths of 470 and 505 nm and T1 package type, examples are Farnell's #142 773, Radio Spare's #235 9900 and American Bright Optoelectronics Inc.'s BL BH3PW1.

[0022] A sixth suitable type of LED is gallium nitride/silicon (GaN/Si), with an emission wavelength of 430 nm. One commercial example is Siemens LB3336 (also known as RS #284 1386).

[0023] Each of the above LED types is selected to have an emission spectrum substantially coincident with the absorption spectrum of one or more of the following common photosensitizers given below in Table 1, and therefore embodiments having such LED's are suitable for PDT. For example, Figure 9 shows the absorption spectrum of PpIX, including peaks at 505nm, 545 nm, 580 nm and 633 nm. Inset are the emission spectra, in units of peak intensity and on the same wavelength axis, of LED part no. HPWA DL00 with a peak at 590 nm and LED part no. HPWT DH00 with a peak at 630 nm, the peaks having sufficient breadth to give a substantial overlap with the 580 nm and 633 nm peaks respectively in the absorption spectrum of PpIX.

Table 1

Photosensitizer	Red absorption Band (nm)	Red Peak (nm)	Blue/Green Peak (nm)
Naphthalocyanines	780-810		
Chalcogenopyrilium dyes	780-820		
Phthalocyanines (e.g. ZnII Pc)	670-720	690	
Tin etiopurpurin ($SnET_2$)	660-710	660-665	447
Chlorins (e.g. N-Aspartyl chlorin e6 or NPe6)	660-700	664	

Table 1 (continued)

Photosensitizer	Red absorption Band (nm)	Red Peak (nm)	Blue/Green Peak (nm)
Benzoporphyrin derivative (BPD)		685/690	456
Lutetium texaphrin (Lu-Tex)		735	
Al(S_1/S_2/S_3/S_4) Pc	660-710	670/685	410, 480
Photofrin		625/630	405
Protoporphyrin IX (PpIX) - from 5/δAminolaevulinic Acid (5ALA)		635	410, 505, 540, 580
Tetra m-hydroxyphenyl Chlorin (mTHPC)		650	440, 525

[0024] The discrete LED array may comprise more than one different type of LED, each with different emission spectra, selected to match different absorption bands of the selected photosensitizer. Each type of LED may be switched independently. The penetration depth (i.e. the depth at which the intensity has been attenuated to e^{-1}) may also be varied by switching on only one type of LED in the array so as to select a suitable emission band, since the penetration depth is a function of the wavelength.

[0025] The LED array may be composed of individually switchable spatially distinct segments of LED's. Selected segments may be switched on so as to treat a selected area of the patient within the overall area of the matrix array.

[0026] The lamp may include an electro-optical detector arranged to monitor the light dose delivered and to switch off the light emission when a target dose is reached. Alternatively, or additionally, the detector is arranged to monitor the instantaneous light intensity and to vary the electrical power supplied to the tubes so as to maintain the intensity within predetermined limits, and/or to switch off the light emission if a maximum limit is exceeded.

[0027] In tests performed by the inventor, the efficacy of PDT using red (approximately 630 nm) emission from LED's was established in *in-vivo* comparative studies using a sub-cutaneous mammary tumour regrowth delay assay. Using radiobiological end-points, it was shown that the solid-state prototype efficacies were comparable to that of expensive conventional lasers for PDT (i.e. no significant difference, p=0.21). These results were confirmed in further clinical studies in the treatment of Bowen's disease and basal cell carcinomas where comparative complete response rates were achieved as compared to laser PDT.

Claims

1. A therapeutic light source, comprising an array of light-emitting diodes (L) arranged so that light from the light-emitting diodes is incident directly on the treatment field with an output intensity of at least 10 mW/cm^2 and a spatial intensity fluctuation of 10% or less, and means (F, H) for cooling the diodes by forced air convection, wherein the diodes are thermally coupled to an array of individual heatsinks (h).

2. A light source as claimed in claim 1, wherein the spatial intensity fluctuation is 6% or less.

3. A light source as claimed in claim 1 or claim 2, wherein the light-emitting diodes are mounted discretely.

4. A light source as claimed in claim 3, wherein the light-emitting diodes are electrically connected in a parallel-series matrix.

5. A light source as claimed in any preceding claim, wherein the light-emitting diodes and the heatsinks are mounted on opposite sides of a support plate.

6. A light source as claimed in claim 5, wherein the support plate is perforated to allow air to flow around the heatsinks and light-emitting diodes.

7. A therapeutic light source as claimed in any preceding claim, wherein the light-emitting diodes having emission wavelengths within the range 550 to 660 nm.

8. A light source as claimed in claim 7, wherein the emission wavelengths are within the range 590 to 640 nm.

9. A light source as claimed in claim 8, wherein the diodes are of aluminium indium gallium phosphide/gallium phosphide die material.

10. A light source as claimed in claim 7, wherein the emission wavelengths are within the range 560 to 644 nm.

11. A light source as claimed in claim 10, wherein the diodes are of aluminium indium gallium phosphide/gallium arsenic die material.

12. A light source as claimed in claim 7, wherein the emission wavelengths are within the range 650 to 660 nm.

13. A light source as claimed in claim 12, wherein the diodes are of aluminium gallium arsenic die material.

14. A light source as claimed in claim 7, wherein the emission wavelengths are within the range 550 to 570 nm.

15. A light source as claimed in claim 14, wherein the diodes are of gallium phosphide die material.

16. A therapeutic light source as claimed in any one of claims 1 to 6, wherein the diodes have peak emission spectra of approximately 470 mn, 505 nm or 525 mn.

17. A light source as claimed in claim 16, wherein the diodes are of indium gallium nitride die material.

18. A therapeutic light source as claimed in any one of claims 1 to 6, wherein the diodes have peak emission spectra of approximately 430 mn.

19. A light source as claimed in claim 18, wherein the diodes are of gallium nitride/silicon die material.

20. Use of a light source as claimed in any preceding claim, for cosmetic treatment of a patient, wherein the cosmetic treatment comprises skin rejuvenation or wrinkle removal.

Patentansprüche

1. Therapeutische Lichtquelle umfassend eine Anordnung von Leuchtdioden (L), die so angeordnet sind, daß Licht aus den Leuchtdioden mit einer Ausgangsintensität von mindestens 10 mW/cm^2 und einer räumlichen Intensitätsschwankung von höchstens 10% direkt auf das Behandlungsfeld einfällt, sowie eine Einrichtung (F, H) zum Kühlen der Dioden durch Umluftkonvektion, wobei die Dioden mit einer Anordnung individueller Kühlkörper (h) thermisch verbunden sind.

2. Lichtquelle nach Anspruch 1, wobei die räumliche Intensitätsschwankung höchstens 6% beträgt.

3. Lichtquelle nach Anspruch 1 oder 2, wobei die Leuchtdioden einzeln befestigt sind.

4. Lichtquelle nach Anspruch 3, wobei die Leuchtdioden in einer Parallel-Serien-Matrix elektrisch verbunden sind.

5. Lichtquelle nach einem der vorhergehenden Ansprüche, wobei die Leuchtdioden und die Kühlkörper auf gegenüberliegenden Seiten einer Trägerplatte befestigt sind.

6. Lichtquelle nach Anspruch 5, wobei die Trägerplatte perforiert ist, damit Luftströmung um die Kühlkörper und die Leuchtdioden möglich ist.

7. Therapeutische Lichtquelle nach einem der vorhergehenden Ansprüche, wobei die Leuchtdioden Emissionswellenlängen im Bereich von 550 bis 660 nm aufweisen.

8. Lichtquelle nach Anspruch 7, wobei die Emissionswellenlängen im Bereich von 590 bis 640 nm liegen.

9. Lichtquelle nach Anspruch 8, wobei die Dioden aus Aluminium-Indium-Gallium-Phosphid-/Galliumphosphid-Chip-

material sind.

10. Lichtquelle nach Anspruch 7, wobei die Emissionswellenlängen im Bereich von 560 bis 644 nm liegen.

11. Lichtquelle nach Anspruch 10, wobei die Dioden aus Aluminium-Indium-Gallium-Phosphid-/Gallium-Arsen-Chipmaterial sind.

12. Lichtquelle nach Anspruch 7, wobei die Emissionswellenlängen im Bereich von 650 bis 660 nm liegen.

13. Lichtquelle nach Anspruch 12, wobei die Dioden aus Aluminium-Gallium-Arsen-Chipmaterial sind.

14. Lichtquelle nach Anspruch 7, wobei die Emissionswellenlängen im Bereich von 550 bis 570 nm liegen.

15. Lichtquelle nach Anspruch 14, wobei die Dioden aus Galliumphosphid-Chipmaterial sind.

16. Therapeutische Lichtquelle nach einem der Ansprüche 1 bis 6, wobei die Dioden Peaks im Emissionsspektrum bei ungefähr 470 nm, 505 nm oder 525 nm aufweisen.

17. Lichtquelle nach Anspruch 16, wobei die Dioden aus Indium-Gallium-Nitrit-Chipmaterial sind.

18. Therapeutische Lichtquelle nach einem der Ansprüche 1 bis 6, wobei die Dioden Peaks im Emissionsspektrum bei ungefähr 430 nm aufweisen.

19. Lichtquelle nach Anspruch 18, wobei die Dioden aus Galliumnitrit-/Silizium-Chipmaterial sind.

20. Verwendung einer Lichtquelle nach einem der vorhergehenden Ansprüche zur kosmetischen Behandlung eines Patienten, wobei die kosmetische Behandlung Hautverjüngung oder Faltenentfernung umfaßt.

Revendications

1. Source de lumière thérapeutique comprenant un groupement de diodes luminescentes (L) disposées de façon que la lumière qu'elles émettent soit.directement incidente sur le site à traiter avec une intensité de sortie d'au moins 10 mW/cm^2 et une fluctuation d'intensité spatiale de 10% ou moins, et des moyens (I, H) pour refroidir les diodes par une convection d'air forcée, les diodes étant reliées thermiquement à un groupement de dissipateurs de chaleur individuels (h).

2. Source de lumière telle que définie dans la revendication 1, dans laquelle la fluctuation d'intensité spatiale est de 6% ou moins.

3. Source de lumière telle que définie dans la revendication 1 ou la revendication 2, dans laquelle les diodes luminescentes sont montées de manière discrète.

4. Source de lumière telle que définie dans la revendication 3, dans laquelle les diodes luminescentes sont reliées électriquement sous la forme d'une matrice parallèle série.

5. Source de lumière telle que définie dans l'une quelconque des revendications précédentes, dans laquelle les diodes luminescentes et les dissipateurs de chaleur sont montés sur des côtés opposés d'une plaque de support.

6. Source de lumière telle que définie dans la revendication 5, dans laquelle la plaque de support est perforée pour permettre une circulation d'air autour des dissipateurs de chaleur et des diodes luminescentes.

7. Source de lumière thérapeutique telle que définie dans l'une quelconque des revendications précédentes, dans laquelle les diodes luminescentes ont des longueurs d'onde d'émission qui se situent dans la plage de 550 à 660 nm.

8. Source de lumière telle que définie dans la revendication 7, dans laquelle les longueurs d'onde d'émission se situent dans la plage de 590 à 640 nm.

9. Source de lumière telle que définie dans la revendication 8, dans laquelle les diodes sont formées d'une matière pour puces constituée de phosphure de gallium, d'indium et d'aluminium/phosphure de gallium.

10. Source de lumière telle que définie dans la revendication 7, dans laquelle les longueurs d'onde d'émission se situent dans la plage de 560 à 644 nm.

11. Source de lumière telle que définie dans la revendication 10, dans laquelle les diodes sont formées d'une matière pour puces constituée de phosphure de gallium, d'indium et d'aluminium/arsenic de gallium.

12. Source de lumière telle que définie dans la revendication 7, dans laquelle les longueurs d'onde d'émission se situent dans la plage de 650 à 660 nm.

13. Source de lumière telle que définie dans la revendication 12, dans laquelle les diodes sont formées d'une matière pour puces constituée d'arsenic de gallium et d'aluminium.

14. Source de lumière telle que définie dans la revendication 7, dans laquelle les longueurs d'onde d'émission se situent dans la plage de 550 à 570 nm.

15. Source de lumière telle que définie dans la revendication 14, dans laquelle les diodes sont formées d'une matière pour puces constituée de phosphure de gallium.

16. Source de lumière thérapeutique telle que définie dans l'une quelconque des revendications 1 à 6, dans laquelle les diodes ont des spectres d'émission maximum d'environ 470 nm, 505 nm ou 525 nm.

17. Source de lumière telle que définie dans la revendication 16, dans laquelle les diodes sont formées d'une matière pour puces constituée de nitrure de gallium et d'indium.

18. Source de lumière thérapeutique telle que définie dans l'une quelconque des revendications 1 à 6, dans laquelle les diodes ont des spectres d'émission maximum d'environ 430 nm.

19. Source de lumière telle que définie dans la revendication 18, dans laquelle les diodes sont formées d'une matière pour puces constituée de nitrure de gallium/silicium.

20. Source de lumière telle que définie dans l'une quelconque des revendications précédentes, destinée au traitement cosmétique d'un patient, le traitement cosmétique comprenant le rajeunissement de la peau ou l'élimination des rides.

Fig. 1

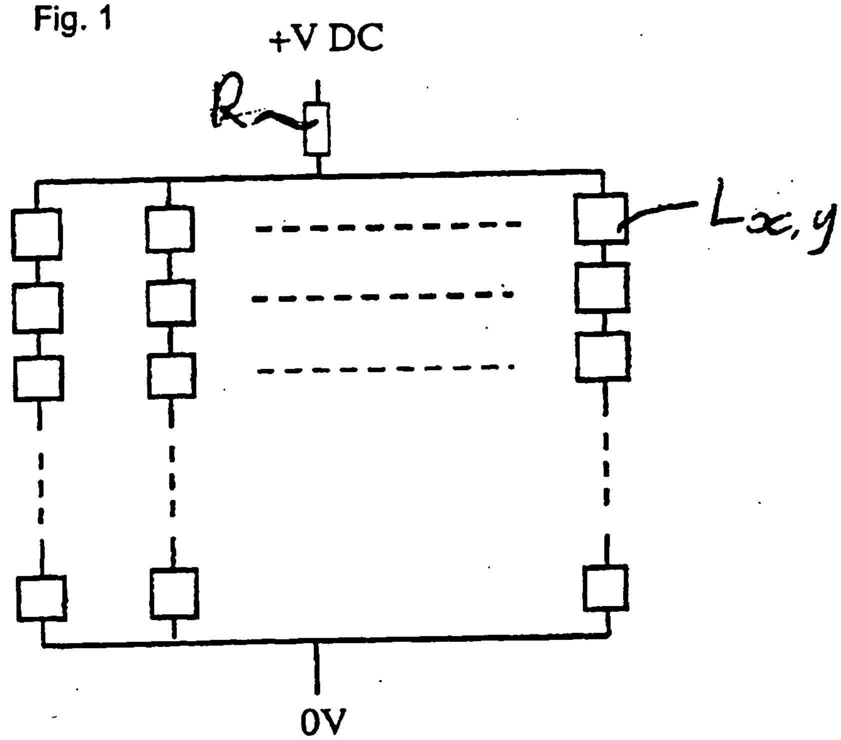


Fig. 2

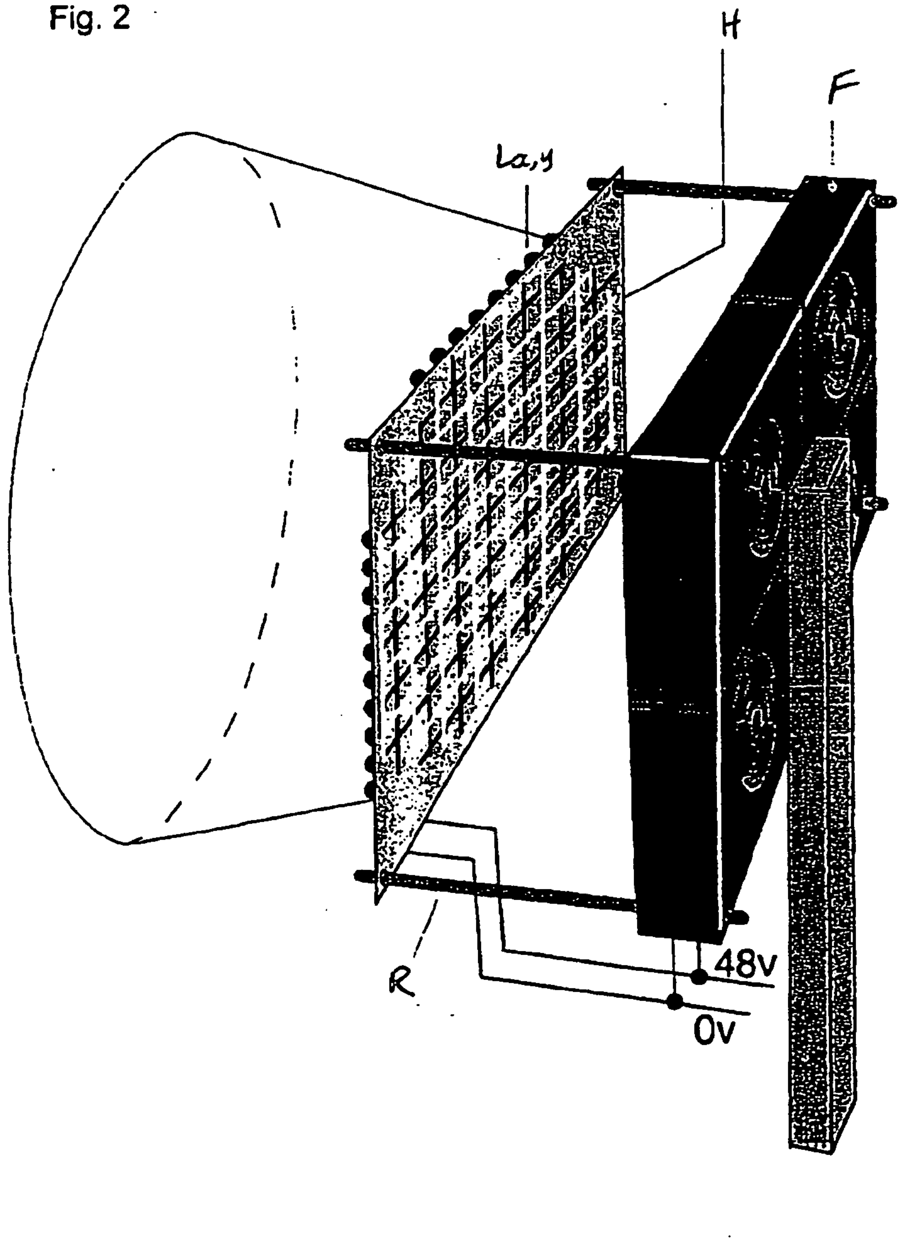


Fig. 3

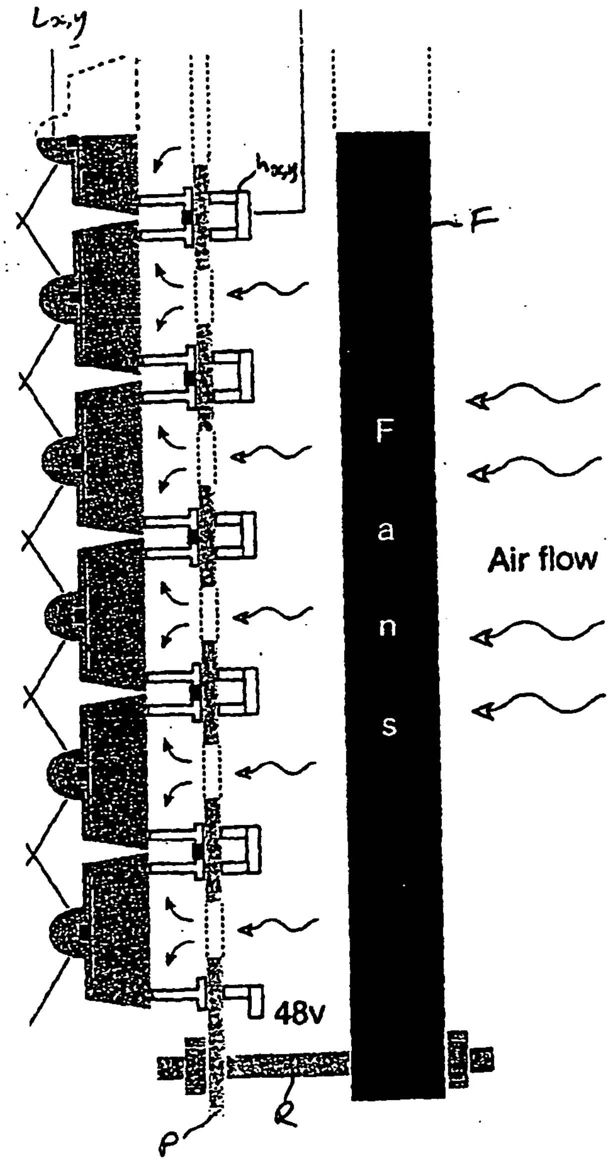


Fig. 4

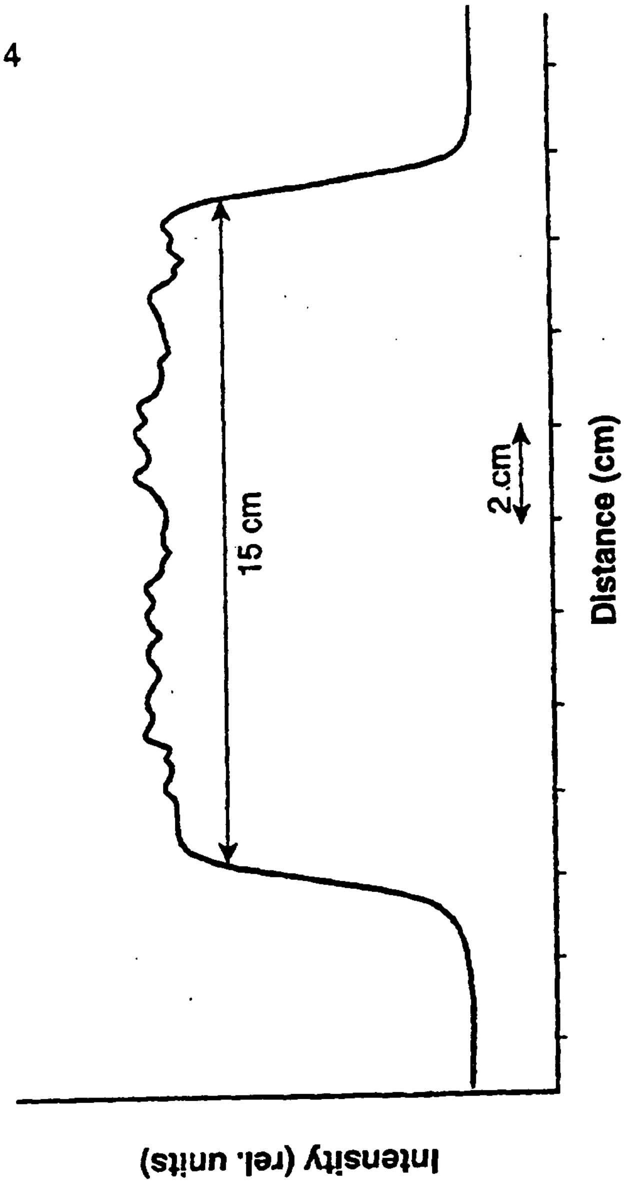
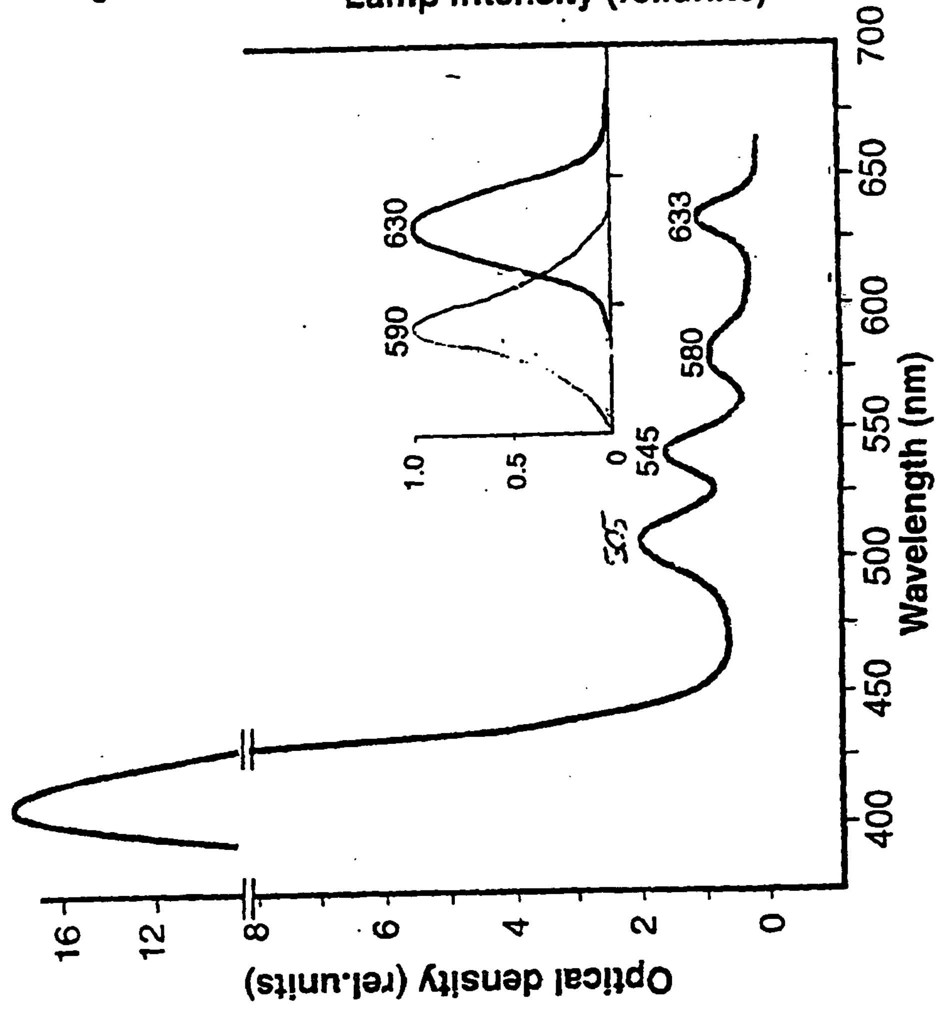


Fig. 5


Lamp intensity (rel.units)
Optical density (rel.units)
Wavelength (nm)
400
450
500
550
600
650
700
0
2
4
6
8
12
16
1.0
0.5
0
590
630
505
545
580
633